# Forestry ecological footprint in China during 1973–2003

HU Xiao-fei[1,4], DAI Li-min[1], GU Hui-yan[1,2], XIONG Xiao-bo[3,4]
[1]*Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, P. R. China*
[2] *College of Forestry of Northeast Forestry University, Harbin 150040, P. R. China*
[3] *Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, P. R. China*
[4] *Graduate School of Chinese Academy of Sciences, Beijing 100039, P. R. China*

**Abstract:** The ecological footprint (EF) model has received much attention as an assessment indicator for sustainable development in recent years. Firstly, the temporal changes of domestic timber production, imports and exports in China were analyzed from 1973 to 2003, the analysis results showed an apparent fluctuation in timber production during 1973–1995 but a decreasing trend during 1995–2002, an increasing trend in timber imports since 1995 especially after the implementation of the Natural Forest Protection Project (NFPP), an decreasing trend year by year in timber exports since 1995. Secondly, this paper presented a time series analysis of actual forest area demand in the sustainable yield and production approach in China from 1973 to 2003, which includes both import and export forest area demand. The results showed the actual forest area demand simulated from the sustainable yield approach was slightly higher than that from the production approach during 1978–1988 and a little lower during 1989–2003; however, the actual forest area demands simulated by these two model approaches were larger than calculations that expressed in conventional forest EF. Meanwhile, the results indicated the forestry development in China during 1978–1988 was unsustainable due to overexploitation of forest stocking volumes, and China's forestry moved toward sustainable development since 1989 because forest resources are exploited at lower rates than they are regenerated. However, compared to forestry developed countries, the forestry development capacity in China is still lower. Finally, based on the model results we analyzed the relationships between forestry EF and the key policies, including trade policy, economic policy and forest conservation programs. In addition, several suggestions about reducing forestry EF and enhancing sustainable forestry development in China are given.
**Keywords**: Ecological footprint; Actual area demand; Sustainable forestry; China
**CLC number**: S718.5 **Document code**: B **Article ID**: 1007-662X(2006)02-0087-06

## Introduction

Sustainable development has gained an increasing attention since the Brundtland Report in 1987 and the United Nations Conference on Environment and Development in 1992 (Hanley *et al*. 1999; Xu & Zhang 2000). Meanwhile, various international forest policy initiatives, such as the intergovernmental Forum on Forests of the United Nations Commission on Sustainable Development and the 6th World Forestry Congress in 1997, had provided the framework for formulating a current and global definition of sustainable forestry and developed corresponding assessment systems due to the forest ecosystem's great functions such as providing wood production, decreasing soil and water erosion, regulating water flow and quality, maintaining biodiversity, protecting species, mitigating greenhouse effect and so on (Jiang 2000). In China, implementation of sustainable forestry was also an important and difficult task (Li 2004). The concept of sustainable forestry and its assessment system were developed with human recognition and scientific advancement since the United Nations Conference on Environment and Development in 1992. By now, many indicators, including ecological, economical and social indicators, have been used to assess forestry sustainability (Jiang 2000). However, those indicator systems were too complex and the indicator data were hard to obtain. In addition, a region had its different indicator system from others, which made assessment results of different countries or regions incomparable. It is necessary to develop an integrated evaluation system that incorporates all the indicators of forestry sustainability.

The ecological footprint (EF) model has gained much attention in the sustainability assessment since it was introduced during the mid-1990's (Wackernagel *et al.* 1996, 1998, 1999, 2004; van Vuuren & Smeets 2000; Erb 2004). EF model represents the areas of land and water required to produce the goods and services for satisfying the consumption of a defined human population or economy and to provide environmental assimilation capacity for keeping its environmental quality at a given level (Wackernagel & Rees 1996; Ferng 2001). EF model is popular because it offers a simple but comprehensive way for evaluating sustainability (Wackernagel *et al*. 1999, 2004). It has frequently been used as one of the sustainability assessment indicators at the global, national, regional or personal levels (van Vuuren & Smeets 2000), and it is proved that it is a useful tool for cross-country comparisons because it makes the consumption levels of different countries comparable (Wackernagel *et al.* 1999; Erb 2004). In addition, the results gotten from EF model analysis are easy to be repeated. Despite the above merits, EF model, as a sustainable development indicator, also has its shortcomings: First, EF model can not distinguish between sustainable and unsustainable land-use patterns (Ferguson 1999). Second, land, for example forestry land, has multiple functions, but only one function is taken into account in many calculations of EF model, which is an obvious obstacle in EF model application (van Vuuren & Smeets 2000). Third, some potentially area-demanding activities are not often covered by the calcula-

**Foundation item**: This paper was supported by National Natural Science Foundation of China (70373044 & 30470302) and Rejuvenation Northeast Program of CAS.
**Biography**: HU Xiao-fei (1974-), female, postgraduate student in the Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, P.R. China. E-mail: huxiaofei03@hotmail.com
**Received date**: 2005-10-28; **Accepted date**: 2005-12-28
**Responsible editor**: Song Funan

tion (Erb 2004).

Recently, research advances of EF models at the three following aspects give us an opportunity to assess forestry sustainability during the past 30 years in China. Firstly, increasing attention is paid on new applications of the EF model in tourism and forestry (Hunter 2002; Wackernagel *et al.* 2004; Zhu *et al.* 2004). Secondly, EF of a country at one time does not reflect the dynamic changes of socio-economic and ecological systems. In order to get useful information for sustainability, several decadal EF models have been developed (Haberl *et al.* 2001; Erb 2004; Wackernagel *et al.* 2004). Thirdly, in conventional EF model, the approximation of bioproductive area is expressed as global average yields per hectare, which loses much detail regional information. Haberl *et al* (2001) refined the potential distortions and confusions arising from the use of 'global hectares', and calculated EF of Austria using three yield factors (constant global yield, variable global yield, and variable local yield). Wackernagel *et al* (2004) also applied EF model in Austria, Philippines and South Korea using conventional EF approach and actual land area approach. In addition, Erb (2004) assessed the actual area demand in Austria from 1926 to 2000. Estimation of temporal EF changes by means of local yield is becoming a new trend in sustainability assessment (Haberl *et al.* 2001; Erb 2004).

China is a developing country with deficient forest resources. Forestry sustainability is closely related with ecological security and national sustainable development. A series of measures, such as the Natural Forest Protection Project (NFPP), the Grain for Green Project, Forest Tenure Reform, Reform of Forestry Taxation and Charges, Forest Certification, and so on, have been put in practice (Li 2004; Wang *et al.* 2004). However, the problems in the implementation of forestry sustainability still exist, and new approaches to sustainable forestry in China need to be developed. In this paper, our objectives are to: 1) obtain the dynamics of forestry sustainability from 1973 to 2003 using improved EF models, 2) analyze the influencing factors to sustainable forestry, and 3) compare the results of improved EF models to conventional EF models.

## Methods and data

### The summary status of forest resource in China

In order to continuously provide information about the forest resources status in China, the first National Forest Resource Inventory (NFRI) covering the entire China was carried out in 1973–1976. Then, five successive inventories were carried out from 1977 to 2003. Date of six NFRI is listed in Table 1 (Ministry of Forestry 1977, 1982, 1990, 1994; State Forestry Administration 2000, 2005). The second NFRI showed that the forest area decreased 5.7% compared with the first one, and timber was harvested at rates exceeding its production. In this period, the central government and people gradually realized the importance of forests to the environment, and thus tremendous afforestation efforts were made. According to the sixth NFRI (1999–2003), the current forest area in China is 174.91 million $hm^2$, stocking volume is 12.46 billion $m^3$, with forest coverage of 18.21%. Compared with the second NFRI, the forest area increased by 60 million $hm^2$, with an average annual growth of 2.4 million $hm^2$; forest coverage increased by 6.2%, with an average annual growth of 0.25%; the forest stocking volume increases by 3.43 billion $m^3$, with an average annual increase of 0.14 billion $m^3$ (Ministry of Forestry 1982; State Forestry Administration 2005). Although China's forest area ranked the fifth and forest stocking volumes ranked seventh around the world, there are only 0.132 $hm^2$ of forest area and 9.42 $m^3$ of forest stocking volume per capita on average, which are only 22% and 13% of the global average, respectively (FAO 2003; State Forestry Administration 2005). China is still a country with deficient forest resources.

**Table 1. The changes of forest resources in China from 1973 to 2003**

| Forest inventories | Inventory periods | Forest area ($10^8$ $hm^2$) | Forest stock volume ($10^8$ $m^{3)}$ | Forest coverage (%) |
|---|---|---|---|---|
| First | 1973-1976 | 1.22 | 86.56 | 12.7 |
| Second | 1977-1981 | 1.15 | 90.28 | 12.0 |
| Third | 1984-1988 | 1.25 | 91.41 | 12.9 |
| Fourth | 1989-1993 | 1.34 | 101.37 | 13.9 |
| Fifth | 1994-1998 | 1.59 | 112.67 | 16.6 |
| Sixth | 1999-2003 | 1.75 | 124.56 | 18.2 |

### Methods

There are six categories of biologically productive areas in conventional ecological footprint model: cropland, pasture, forest, built-up land, fossil fuel, and sea (Wackernagel & Rees 1996). Forest is different from cropland in that forests consist mainly of perennial plants, and timber harvesting is not always equal to wood increment (Erb 2004). Furthermore, forest productivity of China is greatly lower than that of global average. In order to obtain the area needed to support the resource consumption of a defined community based on physical hectares, some research has adjusted conventional EF to actual land demand. Actual land demands differ from the conventional EF in that they are not normalized according to global average yields, so no equivalent factors or yield factors are used in this calculation (Erb 2004; Wackernagel *et al.* 2004). Equation of assessing the actual land demand is displayed below:

$$ef = \sum A_i = \sum (P_i + I_i - E_i)/Y_i$$

where $ef$ is the actual forest area demand of China in a specific year, $P_i$ the domestic production of forest products in tones (t) or cubic meters ($m^3$), $I_i$ the imports, $E_i$ the exports, $Y_i$ the country-specific yields, and the variable $i$ is consumption item types. In this paper, the actual forest area demand is calculated by two methods. The first method based on harvesting per hectare (hereafter call 'production approach'), and the second method based on wood increment per hectare (hereafter call 'sustainable yield approach') (Erb 2004). Without comprehensive data on forest products trade between countries, local yields are used to calculate the forest area of imports and exports.

The actual forest demand area of China is the area required to produce the consumed wood products in China, which include all the fuelwood, roundwood (mainly in the form of sawnwood, wood-based panels), wood pulp, paper and paperboard. All the processed products are converted into roundwood equivalent (RWE). RWE is the volume of roundwood required to produce a given volume of processed timber or manufactured product (Zhu *et al.* 2004), which makes it possible to get more accurate estimates of real consumption. In this study, conversion factor, which represents the ratio between cubic meter of roundwood and cubic meter of forest wood product, is used as follows: the conversion factor of sawnwood is 1.43, wood-based panel is 2.0 and wood pulp, paper and paperboard are all 4.0 (Lin 1999). Multiplication of processed or manufactured wood product

amount by conversion factor is RWE. Ratio of forest harvest, which is the ratio of the timber yields to total consumption forest stocking volume, is assumed as 0.6 (Newsroom of China forestry yearbook 1987–1994; Ministry of forestry 1995–1998; State forestry administration 1999–2004).

**Data sources and treatments**

In this paper, official statistics on commercial timber production, imports and exports are obtained from China forestry yearbooks (Newsroom of China forestry yearbook 1987–1994; Ministry of forestry 1995–1998; State forestry administration 1999–2004). Data about the domestic forest resource consumption from 1985–1995 (excluding 1986, 1987) are obtained from China forestry yearbooks. Others (excluding 1973–1976) are from NFRI (Ministry of Forestry 1982, 1990, 1994; State Forestry Administration 2000, 2005). Owing to lack of 1973–1976 data of China forest resource increment and total forest resources consumption, we assumed wood increment per hectare in 1973–1976 was equal to that in the second NFRI and deduced its consumption from the change of total forest stocking volume between two NFRI. Majority of data on imports and exports of forestry products from 1973 to 2003 had been obtained from China forestry yearbooks (Newsroom of China forestry yearbook 1987–1994; Ministry of forestry 1995–1998; State forestry administration 1999–2004) and China forestry development report (State forestry administration 2001–2004); additional data from Feng *et al* (1999) and Zhu *et al* (2004). Firstly, the actual forest area demand of China expressed in physical hectares is calculated by production approach and sustainable yield approach. Secondly, this result is compared with that of conventional EF approach based on global hectares.

## Results

**Temporal changes of domestic timber production, imports and exports**

The dynamic changes of domestic timber production in China showed an apparent fluctuation during 1973–2003 (Fig. 1). Timber production increased steadily in 1973–1979, decreased slightly in 1980–1982, increased again in 1983–1986. During these 13 years (from 1973 to 1986), timber production increased 1.46 times (from 44.67 million $m^3$ in 1973 to 65.02 million $m^3$ in 1986) due to improved living standards and growing population, which resulted in great pressure on the China's limited forest resources. In order to change the status of forest resource over-exploitation and promote the sustainable forestry, the ministry of forestry began to carry out allowable annual harvesting in 1987, so the timber production decreased sharply in the following three years. However, the timber production increased significantly from 1990 to 1995 due to the needs of economy development in China, which accelerated the decline of forest resources. The government recognized the role of forest resources in national security and environmental protection, and adjusted the related forestry policies. Timber production had been gradually declined especially after the implementation of NFPP (Zhang *et al*. 2000), reaching a low area of 44.36 million $m^3$ in 2002, and then increasing slightly to 47.59 million $m^3$ in 2003.

The dynamics of timber imports and exports also showed a fluctuation during 1973–2003 (Fig. 1). The timber imports during 1980–1990 and 1998–2003 were higher than other periods. China experienced a rapid economic growth and population increase in the 1980s, which might contribute to the growing imports. The logging restrictions after the implementation of NFPP and reductions in wood products import tariffs resulted in fast increases in timber imports during 1998–2003. The fluctuation of timber exports was bigger especially during 1973–1981 and 1988–1995. Meanwhile, the timber exports decreased year by year since 1995, and kept a lower amount since the implementation of NFPP. In a word, China was a net timber importer in our research period except in 1975, and the amount of import timber gradually increased in recent years. In addition, China's rapid increase of imported forest products might have some environmental impacts on the source countries that supply the timber to China, these impacts could be mitigated if supplying countries improved their forest management practices or we exported timber from countries of fast-growing plantations (Zhu *et al.* 2004). Fast-growing plantations have a higher yield than the global average yield, which contributes to less environmental impacts. As more and more countries realized the importance of environment and restricted timber export, China should change the dependence degrees on foreign countries through developing its own fast-growing plantations and improving forest management practices.

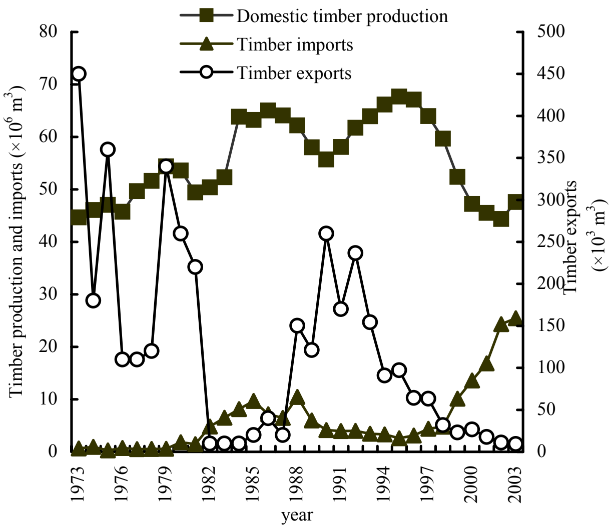


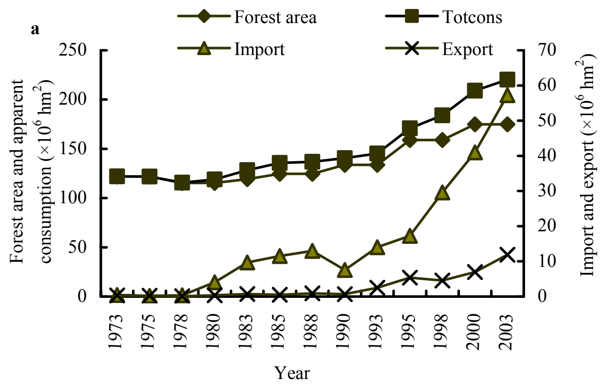

**Fig. 1 The dynamics of domestic timber production, imports and exports in China from 1973 to 2003.** Data are obtained from China forestry yearbook, the data represent official plan of industrial timber production, and they don't take into account large quantities of over-quota-logging.

**Actual forest area demands in China**

Although the actual forest area demand simulated from the sustainable yield approach was slightly higher than that from the production approach during 1978–1988 and a little lower during 1989–2003, in the whole, there were similar trends for actual forest area demand simulated by both approaches (Fig. 2a and b).

Actual forest area demand showed few changes during 1973–1978. Due to China's rapid economic development and improved living standards, there was a steep increase in the actual forest area demand for domestic apparent consumption since 1978 (Fig. 2). Three different increase phases could be divided by 1993 and 1998, respectively. Two important events happened in 1992 might contribute to this. Firstly, China began to realize that to achieve long-term and sustainable economical and social

development, China economy should be transformed into market economic system in the wake of Deng Xiaoping's visits in Southeast China in 1992; secondly, China taken part in the United Nations Conference on Environment and Development in 1992 and signed the Agenda 21 and Rio declaration, which was a signal of China beginning to seek for a sustainable economic, social and ecological development. These two events in 1992 initiated a lot of changes of governmental policies thereafter 1992, and the effects began to show in 1993. In addition, Chinese government legislated the NFPP to protect existing natural forests from immoderate tree-felling and restore natural forests in ecologically sensitive areas in 1998 (Li 2004). The first phase (during 1978–1993) showed a slow increase tendency with an annual average increase of 1.98 million hm$^2$ in sustainable yield approach and 1.23 million hm$^2$ in production approach, respectively. The second phase (during 1993–1998) showed a medium increase tendency with an annual average increase of 7.75 million hm$^2$ in sustainable yield approach and 8.22 million hm$^2$ in production approach, respectively. The third phase (during 1998–2003) had a faster increase rate with an annual average increase of 7.25 million hm$^2$ in sustainable yield approach and 9.33 million hm$^2$ in production approach, respectively. There were little differences between the results from two approaches during 1973–1978, but the differences were bigger with increasing time. The forest area required for apparent consumption was 7.4% lower in the sustainable yield approach than in the production approach in 2003.



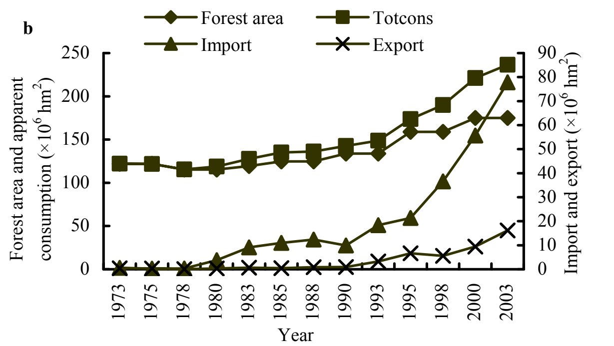




**Fig. 2 Actual forest land demand of China from 1973 to 2003. (a) From the sustainable yield approach, and (b) from the production approach.** Totcons denotes the forest area demand related to domestic apparent consumption, which equals land required for domestic production (including fuelwood and peasant self use timber) plus land required for imports minus land required for exports. Forest area depicts the china's forest area needs for domestic production. Imports depicts total forest area required for import, exports depicts total forest area required for export.

Forest area demands for import were few before the start of economic reforms in 1978. However, there was a steep rise since 1978 (except in 1989–1991) might due to fast population growth, changes of China's foreign policies, production and consumption patterns. The first phase (1978–1993) showed a slow increase with an annual average increase of 0.91 million hm$^2$ in sustainable yield approach and 1.20 million hm$^2$ in production approach, respectively. The second phase (1993–1998) showed a rapid increase with an annual average increase of 3.11 million hm$^2$ in sustainable yield approach and 3.64 million hm$^2$ in production approach, respectively. The third phase (during 1998–2003) had a higher increase rate than that of previous phase both in production approach and in sustainable yields approach. In 2003, the forest area required for import in sustainable yield approach was 73.6% of that in the production approach, which might indicate that wood harvest is substantially lower than wood increment. In addition, forest area demands for import had a decline in 1989–1991, which coincided with China's slower economic development rate in this period.

Forest area demands for export were few compared with domestic apparent consumption before 1992. China exported more and more actual forest area since 1993, increased from 2.5 million hm$^2$ in 1993 to 5.38 million hm$^2$ in 1995, then decreased slowly to 4.55 million hm$^2$ in 1998 from sustainable yield approach. China experienced rapid export growth with 1.47 million hm$^2$ and 5.11 million hm$^2$ increase per year during 1998–2003 in sustainable yield approach and production approach, respectively, which was much higher than the increase rate during 1993–1998. In 2003, the forest area required for export from sustainable yield approach was 4.27 million hm$^2$ lower than that from the production approach. Increase rate of exported forest area was slower than that of import; therefore, China was a net import country.

Fig. 2 also showed that the forest land requirement for domestic apparent consumption was almost equal to the forest area before 1978, but was higher than the forest area from 1978 to 2003. China's main source of timber before 1978 was from domestic production, and foreign trade played a minor role. Since China opened its door to other countries in 1978, imported forest products became bigger and bigger portions of the country's domestic consumption. By 2003, imported forest area had reached 32.9% of total consumption forest area in production approach and reached 25.9% in sustainable yield approach. The increment of timber importation in China contributed to substantial increase in total domestic stocks, which was also showed in the NFRI. Along with the increase in import, China also exported more and more forest products; the exported forest area demand reached 6.8% of total consumption area in 2003 in production approach and 5.4% in sustainable yield approach.

A further analysis showed that exports and imports were least before 1978 coincided with China's close-door policy. Since China opened its door to other countries in 1978, China's forest products exports and imports increased with the more interactions with global economy. Imports exceeded exports over the entire analysis periods except in 1975, which might imply that China had no enough domestic forest area to meet the nation's consumption for forest products and made an ecological trade deficit. Especially, after the implementation of the NFPP in 1998, the domestic annual forest consumption and commercial timber production were reduced sharply, and thus to meet the demands of nation's consumption, more and more forest products were imported from other countries. It was clear that the combination of China's rapid economic development, improved living stan-

dards, increased population, China's forest policy reforms and international or domestic market forces had led to a sharp change in the actual forest area demand over the time period of 1973–2003.

**Model results comparisons**

Comparison of actual forest area demand with conventional forest EF calculation for China is showed in Fig. 3. Methods of global yield were described in Wackernagel *et al* (1999), and import and export EF were calculated using the global yields. Although lack of available data on global forest yields time series, we do think that the global forest yields in the study time period would have a small change, and therefore, the forest yields is used based on Wackernagel *et al* (1999).

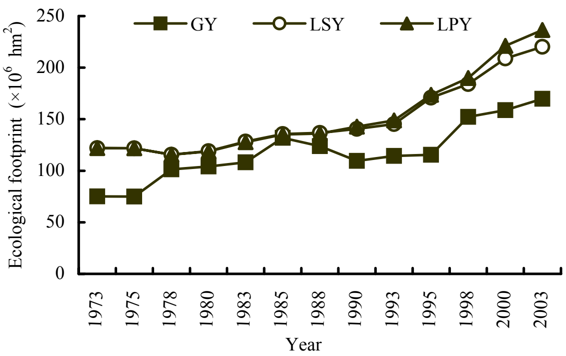



**Fig. 3 Comparison of forest area demand to conventional EF calculation for China from 1973 to 2003**. Methods of GY are described in Wackernagel (1999), import and export yields were calculated using the global yields. GY denote forest ecological footprint using global yield, LSY and LPY denote actual forest land demand of China from 1973 to 2003 according to the sustainable yield approach and the production approach, respectively.

From Fig. 3, we can see forest area demands in sustainable yield approach and the production approach are larger than calculations that expressed in conventional forest EF. The reasons might be as follows in brief: firstly, conventional EF method is normalized according to forest productivity, while the results in this paper are real forest area demand. Secondly, there is yield difference between China and the world. China's forests productivity is lower than world average forests productivity. Global yield methods showed different change trends about forest EF that there was a steady increase during 1973–1985, but a slightly decrease during 1985–1990, which possibly because China introduced the allowable annual cut (AAC) in June 1985 and more and more countries restricted log export in the late 1980s. The forest EF increased again in the 1990s, especially after the implementation of the NFPP in 1998, reaching a high forest EF of 169.76 million $hm^2$ in 2003 that was 226% higher than that in 1973. However, the results from sustainable yield and production approaches showed almost steady increase over the whole period, and the actual forest area demands for consumption in 2003 were 1.81 and 1.94 times higher than those in 1973 from sustainable yield and production approaches, respectively. The actual area demand calculated by the production approach was lower than that by sustainable yield approach from 1978 to 1988, which might indicate overexploitation of forest stocking volumes; however, it was higher from 1989 to 2003, which might indicate that forest resources are exploited at lower rates than they are regenerated. The sixth NFRI results showed China forest resources consumption was only 70% of the increment of its forest during 1999–2003, which result in the forest area required for apparent consumption (Totcons) in sustainable yield approach was 16.28 million lower than the results from the production approach in 2003. Not only is the area for apparent consumption notably smaller in the two methods, area demand for imports and exports also differed considerably: forest area and forest stocking volume were increased.

## Conclusions and discussion

This paper assessed the actual forest area demand of China from 1973 to 2003 using both production approach and sustainable yield approach; both approaches show similar trends of actual forest area demand over time. Three different increase phases could be divided by 1993 and 1998. Actual forest area demand in the first phase (during 1978–1993) showed a slow increase tendency, the second phase (1993–1998) showed a rapid increase, the third phase (during 1998–2003) had a higher increase rate than that of previous phase in production approach and had a little lower increase rate than that of second phase in sustainable yields approach. There were similar trends for import forest area demand simulated by these two approaches. The first phase (1978–1993) had a steep rise except in 1989–1991, the later two phases (during 1993–1998 and 1998–2003) had a faster increase rate, and the third phase (during 1998–2003) had a higher increase rate than that of previous phase both in production approach and in sustainable yields approach. Forest area demands for export were few compared with domestic apparent consumption before 1992. China exported more and more actual forest area since 1993. The results showed the actual forest area demand simulated from the sustainable yield approach was slightly higher than that from the production approach during 1978–1988, and a little lower during 1989–2003, which indicated the forestry development in China during 1978–1988 was unsustainable due to overexploitation of forest stocking volumes, and China's forestry moved toward sustainable development since 1989 because forest resources were exploited at lower rates than they were regenerated. Results also showed actual forest area demands from production approach and sustainable yield approach were higher than the calculation of conventional EF model in global yield. China's forests productivity was lower than world average forests productivity. Compared with forestry developed countries, the forestry development capacity in China is still lower.

Forest area demand has close relations with two factors: total consumption amount of wood products and the yield per hectare. In order to reduce actual forest area demand, three measures might be taken: (1) China should develop high-productivity forest plantations such as fast-growing plantations and improve its own forest management practices. (2) China central government should continue to perform family planning policy and encourage environmentally friendly resource-saving consumption pattern. (3) China's forest industries should promote the development of the technologies and equipment that increase the use efficiency of the forest resources, as well as promote the recycling and reuse of wastepaper, plywood and other wood products.

China's expanding demand for wood is stimulating forest products importation from many countries. Being short of temporal and spatial yield per hectare data for the prospective im-

portation countries of China, it is difficult to show exactly where the imported actual forest area from and how much of actual forest area are imported from respective countries, we could not evaluate their impacts on other countries. How to integrate spatial information to EF model needs further research.

Sustainable development is a complicated issue, EF indicators reveal little about the social and economic aspects of sustainability. In order to assess sustainable development more comprehensively, the future researches might pay more attention to the combining actual area demand with other indicator systems, for example, human utilization of net primary production and energy value analysis.

## Acknowledgements

We thank Dr. Chen Fu-sheng, Chen Guang-sheng and Singh N. Anand for their valuable comments on this paper.

## References

Erb, K.H. 2004. Actual land demand of Austria 1926-2000: a variation on ecological footprint assessments [J]. Land Use Policy, **21**(3): 247–259.

Feng Guoqiang., Zhang Lei., Cui Ping. 1999. Wood aggregation demand and supply and market structure in China [J]. Forestry Economics, **5**: 61–74. (in Chinese)

Ferguson, A.R.B. 1999. The logical foundations of ecological footprints [J]. Environment, Development and Sustainability, **1**(2): 149–156.

Ferng, J-J. 2001. Using composition of land multiplier to estimate ecological footprints associated with production activity [J]. Ecological Economics, **37**(2): 159–172.

FAO. 2003. State of the world's forests 2003 [M]. Rome: FAO. Forestry Department, p132–135.

Haberl, H., Erb, K., Krausmann, F. 2001. How to calculate and interpret ecological footprints for long periods of time: the case of Austria 1926-1995 [J]. Ecological Economics*,* **38**(1): 25–45.

Hanley, N., Moffatt, I., Faichney, R., *et al*. 1999. Measuring sustainability: A time series of alternative indicators for Scotland [J]. Ecological Economic, **28**(1): 55–73.

Hunter, C. 2002. Sustainable tourism and the touristic ecological footprint [J]. Environment, Development and Sustainability, **4**: 7–20.

Jiang Zehui. 2000. Modern forestry of China [M]. Beijing: China's Forestry Publishing House, p5–65. (in Chinese)

Li Wenhua. 2004. Degradation and restoration of forest ecosystems in china [J]. Forest Ecology and Management, **201**: 33–41.

Lin Fengming. 1999. Product, consumption and trade and its development trends of timber and main forest products in China in 2010 [J]. Forest Science and Technology, **6**: 3–6. (in Chinese)

Ministry of Forestry. 1977. China Forest Resources Inventory from 1973 to 1976 [M]. Beijing: China Forestry Publishing House, p45–126. (in Chinese)

Ministry of Forestry. 1982. China Forest Resources Inventory from 1977 to 1981 [M]. Beijing: China Forestry Publishing House, p23–168. (in Chinese)

Ministry of Forestry. 1990. China Forest Resources Inventory from 1984 to 1988 [M]. Beijing: China Forestry Publishing House. (in Chinese)

Ministry of Forestry. 1994. China Forest Resources Inventory from 1989 to 1993 [M]. Beijing: China Forestry Publishing House. (in Chinese)

Ministry of Forestry. 1995-1998. China Forestry Yearbook: 1994-1997 [M]. Beijing: China Forestry Publishing House. (in Chinese)

Monfreda, C., Wackernagel, M., Deumling, D. 2004. Establishing national natural capital accounts based on detailed ecological footprint and biological capacity assessments [J]. Land Use Policy, **21**: 231–246.

Newsroom of China forestry yearbook. 1987-1994. China Forestry Yearbook: 1986-1993 [M]. Beijing: China Forestry Publishing House. (in Chinese)

State Forestry Administration. 1999-2004. China Forestry Yearbook: 1998-2003 [M]. Beijing: China Forestry Publishing House. (in Chinese)

State Forestry Administration. 2000. China Forest Resources Inventory from 1994 to 1998 [M]. Beijing: China Forestry Publishing House. (in Chinese)

State Forestry Administration. 2001-2004. China Forestry Development Report: 2001-2004 [M]. Beijing: China Forestry Publishing House. (in Chinese)

State Forestry Administration. 2005. China Forest Resources Report [M]. Beijing: China Forestry Publishing House, p1–38. (in Chinese)

Van Vuuren, D. P., Smeets, E. M. W. 2000. Ecological footprints of Benin, Bhutan, Costa Rica and the Netherlands [J]. Ecological Economics, **34**(1): 115–130.

Wackernagel, M., Monfreda, C., Erb, K.H. 2004. Ecological footprint time series of Austria, the Philippines, and South Korea for 1961-1999: comparing the conventional approach to the 'actual land area' approach [J]. Land Use Policy, **21**(3): 261–269.

Wackernagel, M., Onisto, L., Bello, P., *et a1*. l999. National natural capital accounting with the ecological footprint concept [J]. Ecological Economics*,* **29**(3): 375–390.

Wackernagel, M., Rees, W. 1996. Our ecological footprint: reducing human impact on the earth [M]. Philadelphia: New Society Publishers.

Wackernagel, M., Yount, J.D. 1998. The ecological footprint: An indicator of progress toward regional sustainability [J]. Environmental Monitoring and Assessment, **51**: 511–529.

Wang, S., Van Kooten, G.C., Wilson, B.M. 2004. Mosaic of reform: forest policy in post-1978 China [J]. Forest Policy and Economics, **6**: 71–83.

Xu Zhongmin, Zhang Zhiqiang. 2000. Review indicators measuring sustainable development [J]. China Population, Resources and Environment, **10**(2): 60–64. (in Chinese)

Zhang Peichang, Shao Guofan, Zhao Guang, *et al*. 2000. China's forest policy for the 21st century [J]. Science, **288**: 2135–2136.

Zhu Chunquan, Rodney, T., Feng Guoqiang. 2004. China's wood market, trade and the environment [M]. Beijing: Science Press, p1–61.